Scattering of Acoustic Waves from Ocean Boundaries

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LONG-TERM GOALS

Development of a physical model of high-frequency acoustic interaction with the ocean floor, including penetration through and reflection from smooth and rough water/sediment interfaces, scattering from the interface roughness and volume heterogeneities and propagation within the sediment. The model will aid in the detection and classification of buried mines and improve SONAR performance in shallow water.

OBJECTIVES

1) Determination of the correct physical model of acoustic propagation through ocean sediments and scattering from sediment interfaces through the analysis of in situ measurements.
2) Development of predictive models that can account for the all of the physical processes and variability of acoustic propagation and scattering in ocean environments with special emphasis on propagation in shallow water waveguides and scattering from ocean sediments.
3) Development of the new experimental techniques to measure geo-acoustic parameters in the ocean.

APPROACH

1) *Analysis of the effects of sediment variability on transmission loss by finite element modeling*: Sediment variability including patchiness can have a major effect on propagation loss and reverberation. There have been several models developed to predict propagation loss in these complex environments. The finite element method serves a valuable benchmarking tool to provide ground truth as well as to determine exact solutions for particular environments. Therefore, a patchy finite element propagation model has been developed for both 2D environments and 3D environments with longitudinal invariance.
2) *Inclusion of layering in bottom loss and scattering models*: Previously, finite element models have predicted scattering from ocean bottoms and served as a means to determine the range of validity of approximate models such as perturbation theory and the Kirchhoff approximation. The finite element model has now been extended to include layered fluid and elastic bottoms with and without interface roughness. This model can be compared with navy standard models such as the GeoAcoustic Bottom Interaction Model (GABIM). to determine their range of validity. [Jackson, 2010.]

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3) *Incorporation of the Texas Advanced Computing Center for finite element analysis:* Finite element models require significant computational resources. Until recently, the models have been run on stand-alone servers. However, with the recent release of COMSOL 4.3, new licensing has allowed the models to be run on massively parallel system decreasing run time and increasing the number of degrees of freedom. Graduate student, Bryant Tran, led this effort.

WORK COMPLETED

1) *Analysis of the effects of sediment variability on transmission loss by finite element modeling:* In order to assess the effect of sediment variability on propagation loss, models of clay over sandy sediment with a periodic range dependence were considered. Two such models are shown in Fig. 1. Both of these models have the same geometric mean for the reflection coefficient so for a model such as the energy flux model the propagation loss would be the same. [Holland, 2010] However, as is apparent in Fig. 1, as the variability becomes closer to the length of a wavelength, scattering becomes an important mechanism and increases the propagation loss. In this case, the variability of the in the upper panel has a period of 500 m, the variability in the lower panel has a period of 50 m and the wavelength is 7.5 m.

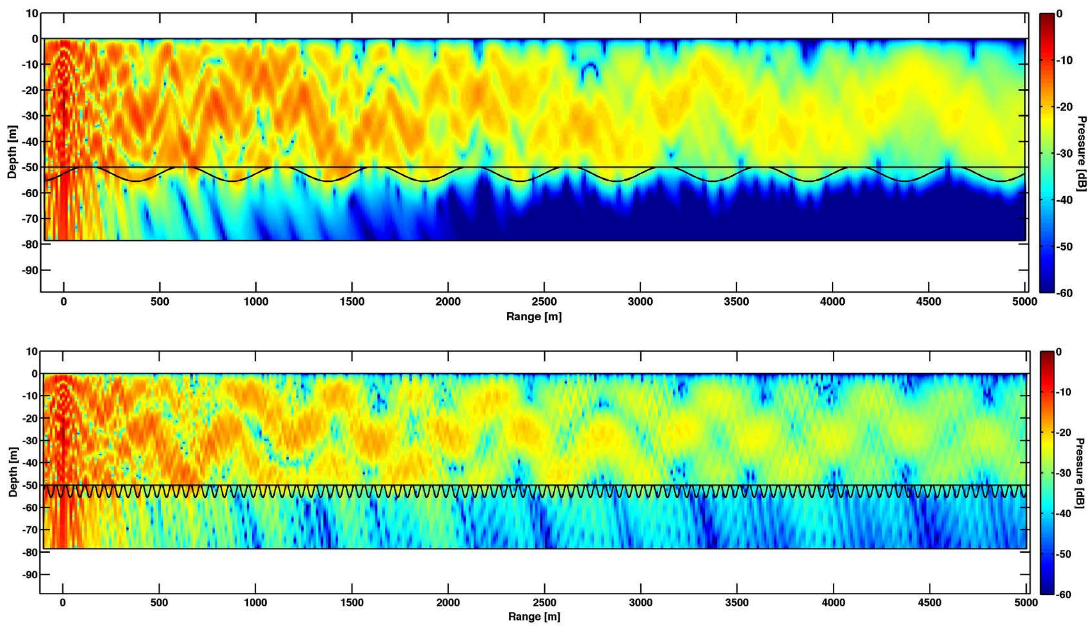

Figure 1: The pressure field for a waveguide with a sediment variability of 500 m (upper panel) and 50 m (lower panel). The sediment is clay over sand and the frequency is 200 Hz.

2) *Inclusion of layering in bottom loss and scattering models*: The finite element scattering model was enhanced to include layering. Because of the many interactions between the layers, the model required nearly an order of magnitude increase in length. Additionally, it was determined that for accurate computations at low angles, two new criteria must be employed. First, because a Gaussian tapered plane wave is employed, the beam waist must satisfy the criteria specified in [Toporkov, 2010], it does not represent a plane wave at the center. The beam waist criteria is:

$$g > \frac{A\sqrt{2}}{k(p/2 - q_i)\cos q_i}$$

Here g is the beam waist, A is a constant, suggested to be 6.64 by the authors, k is the wavenumber and q_i is the incident angle. In addition to the beam waist criteria, the PMLs must be adjusted so that the incoming low angle radiation is not reflected back into the domain. This is accomplished by setting the PML curvature to $\cos(q_i)$. An example of the scattered pressure field for clay over sand model for a Gaussian shaded plane wave at a grazing angle of 52 degrees at 5 kHz is shown in Fig. 2. Note that there is no evidence of reflection from the top or bottom perfectly matched layers, which terminate the domain. Note also the interference pattern in the clay layer for the up and down going waves. Also shown is the field for a rough interface condition. The model can calculate forward and backscattering for any number of layers, both fluid and elastic with and without rough interfaces.

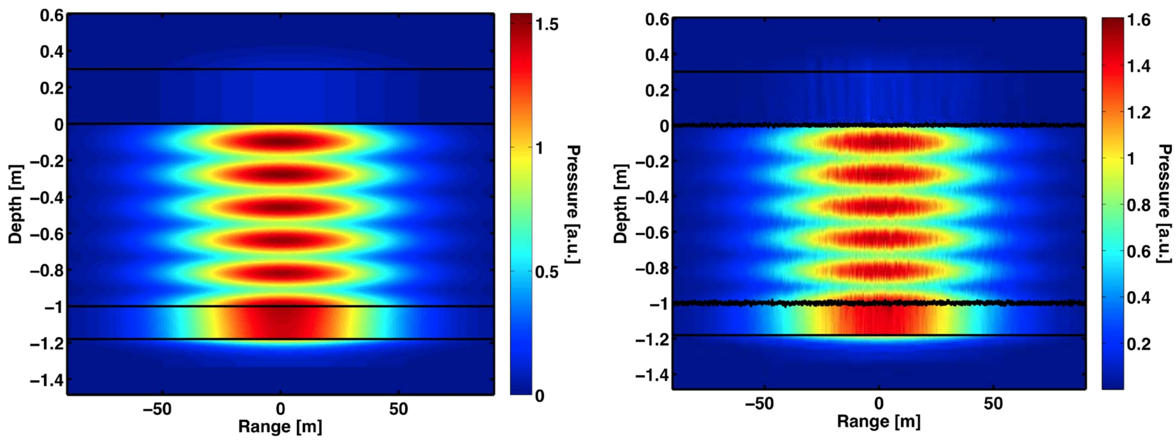

Figure 2: The scattered pressure field for incident Gaussian shaded plane wave. On the left is shown reflection from a water/clay/sand layer. On the right is shown the same geometry with rough power law interfaces. The frequency is 5 kHz.

3) *Incorporation of the Texas Advanced Computing Center for finite element analysis*: Finite element models simulations have been run using the Texas Advanced Computing Center (TACC) supercomputing cluster named Lonestar 4, which was ranked 67th on the top 500 supercomputer rankings in June 2012. Being able to run simulations on this machine gives us the ability to simulate environments in a way that would otherwise be time-prohibitive due to numerical complexity. It also speeds up existing computations by an order of magnitude.

RESULTS

1) *Analysis of the effects of sediment variability on transmission loss by finite element modeling:* The effects of sediment variability on propagation loss for the periodic surface in Fig. 1 are shown in Fig. 3 for a receiver at mid water column depth for both the coherent and incoherent (range

averaged) cases. Note how, although the geometric mean of the reflection coefficient, the waveguide in which the period of the variability was smaller experienced much more loss due to scattering into the bottom sediment. Note also that the location of nulls has shifted for each case especially at longer ranges.

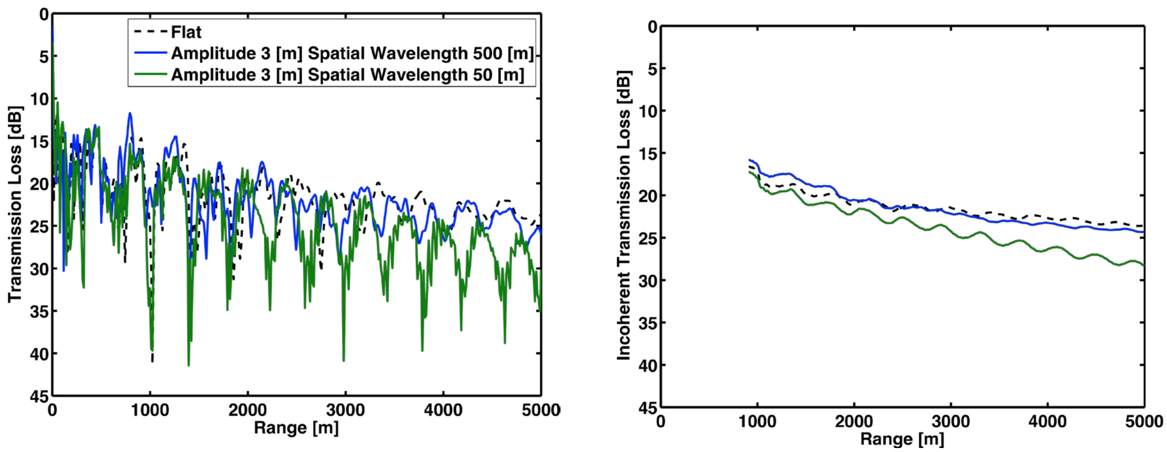

Figure 3: The coherent (left) and incoherent (right) transmission loss for the two cases shown in Fig. 1 for a receiver at mid water depth.

2) *Inclusion of layering in bottom loss and scattering models:* Shown in Fig. 4 is the reflection loss magnitude from a layered clay/sand interface calculated with the finite element model compared with an analytic model for a frequency of 5 kHz. Note the excellent agreement even at low grazing angles. This model will be compared with Navy standard models in order to determine the range of validity of the faster models.

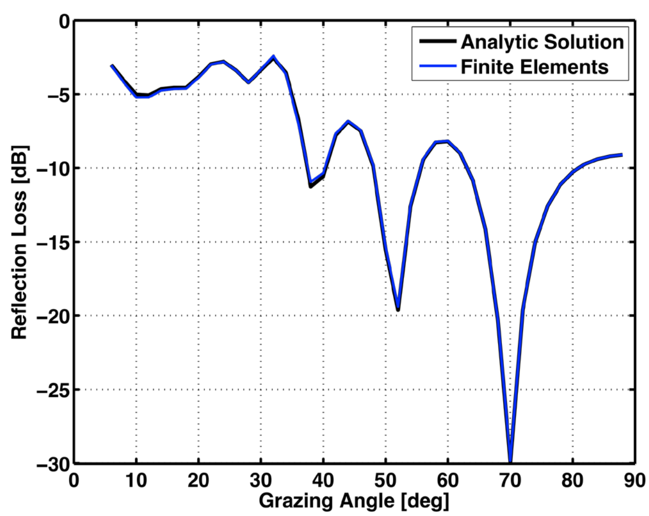

Figure 4: The reflection loss from finite elements and an analytic solution for a flat water/clay/sand interface at 5 kHz.

4) *Incorporation of the Texas Advanced Computing Center for finite element analysis*: An example of the decrease in computational time is a 3D longitudinally invariant model that would ideally take 12 hours to process using conventional methods to just under 1 hour of processing time distributed over 12 nodes. Currently, extracting the data is still cumbersome, but this will be improved in the future.

IMPACT/APPLICATIONS

The finite element reflection loss models could transition into a new high frequency and low frequency reflection loss (LFBL/HFBL) data curves for NAVO based on site specific characteristics. An understanding of normal incident reflection loss is critical to sediment characterization and mine burial prediction.

RELATED PROJECTS

Under the iPUMA Sediment Environmental Estimation (iSEE) program, this group is also developing sediment characterization algorithms for AUV sonars based on the measurements and models previously developed by this program. Additionally, the models developed in this research will be used to increase the fidelity of sonar trainers under the High Fidelity Active Sonar Trainer (HiFAST) program. There will be significant collaboration with Dr. Nicholas Chotiros, particularly for theoretical development of bulk acoustic/sediment modeling and laser roughness measurements.

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